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Exercise Testing: Who, When, and Why?

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Abstract

There are different modalities of exercise testing that can provide valuable information to physicians about patient and athlete fitness and cardiopulmonary status. Cardiopulmonary exercise testing (CPX) is a form of exercise testing that measures ventilatory and gas exchange, heart rate, electrocardiogram, and blood pressures to provide detailed information on the cardiovascular, pulmonary, and muscular systems. This testing allows an accurate quantification of functional capacity/measure of exercise tolerance, diagnosis of cardiopulmonary disease, disease-progression monitoring or response to intervention, and the prescription of exercise and training. CPX directly measures inhaled and exhaled ventilator gases to determine the maximal oxygen uptake, which reflects the body's maximal use of oxygen and defines the limits of the cardiopulmonary system.

CPX is the ideal modality to evaluate causes of exertional fatigue and dyspnea, especially in complex cases in which the etiology could be cardiac, pulmonary, or deconditioning. Exercise tolerance has become an important outcome measure in patients with chronic obstructive pulmonary disease and congestive heart failure, as well as other chronic diseases, and is a well-recognized predictor of mortality. Older athletes or those with underlying medical conditions could benefit from exercise testing for risk stratification and clearance to participate, as well as to help set their training zones and determine their functional limitations.

Introduction

Exercise testing (ET) can be a valuable tool in the assessment of patient functional capacity, diagnosis of cardiopulmonary disease, and the prescription of exercise and training. There are several different modes and modalities available for ET that can provide different types of information to the clinician to help patients/athletes improve their fitness or cardiopulmonary status. Through cardiopulmonary exercise testing (CPX), ventilatory and gas exchange, as well as heart rate, electrocardiogram, and blood pressures, are measured to provide detailed information on the cardiovascular, pulmonary, and muscular systems. The purpose of this article is to review who needs ET, when the testing should occur, which test to perform and why, and how to apply this information in a practical manner.

What Is CPX?

Simply put, ET is used to evaluate the body's reaction to a measured exercise stress. Exercise can elicit cardiovascular responses that may not be present at rest and can be used to assess the function of the cardiovascular system. The most important measure provided by ET is functional capacity. ET can help determine functional capacity by calculating the amount of metabolic equivalents (METs) an individual can perform, with 1 MET defined as an oxygen use of 3.5 mL O_2/kg-min—the energy an average person expends seated at rest.

The reliance on METs, however, significantly overestimates actual oxygen use [1,2]. This measure of exercise quantification is relatively simplistic and does not provide much clinical utility. CPX allows a more dependable assessment of function, as well as an ability to provide prognostic or clinical information by the use of ET with the addition of ventilator gas exchange. CPX directly measures inhaled and exhaled ventilator gases to determine the maximal oxygen uptake (VO_2max), which is a more accurate quantification of functional capacity. This information can then be used for a better functional evaluation in the clinical setting. Furthermore, CPX should be considered the gold standard in evaluating the causes of exercise intolerance in patients with pulmonary and cardiac disease [3].

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The lungs, heart, pulmonary, and systemic circulations form a single circuit for the exchange of respiratory gases between the cells of the body and the environment. Under steady-state conditions, oxygen consumption and carbon dioxide output measured at the mouth are equivalent to oxygen use and carbon dioxide production at the cell. Therefore, external respiration equals internal respiration [4]. CPX capitalizes on this principle and measures the fraction of oxygen and carbon dioxide in expired gas and expired air volume, which can then be used to determine oxygen consumption (VO_2) per unit time, carbon dioxide output (VCO_2), and minute ventilation (VE). From these measures, many clinically relevant parameters can be determined.

ET should be conducted by trained personnel with baseline knowledge of exercise physiology. The American Heart Association states, "Exercise testing of patients should be performed under the supervision of a physician who is trained to conduct exercise tests..." [5]. The degree of supervision needed will be determined by the testing facility and the risk level of the patients. The American College of Sports Medicine (ACSM) recommends that a physician does not need to be present for a person of low risk (1 or fewer risk factors) during ET [6]. In the case of moderate risk, a physician should be present during maximal testing but does not need to be present for submaximal testing. A high-risk individual should have a physician present during any ET [6]. It is recommended that persons trained in Advanced Cardiac Life Support be available during ET as up to 10 myocardial infarctions (MIs) can be expected to occur per 10,000 tests—this risk is greater in those with previous history of coronary artery disease or MI [7]. Although this number does not seem to be very high, preparation will prevent an unnecessary death during testing.

Equipment and Protocols

Performance of CPX requires the ability to measure 3 responses during inspiration and expiration: (1) the concentration of O_2; (2) the concentration of CO_2; and (3) a quantification of ventilation (usually VE, which refers to both tidal volume and respiratory rate). This measurement requires the patient to wear a facemask that covers the mouth and nose or a mouthpiece and a nose clip. CPX software systems can rapidly analyze the inhaled and exhaled gases.

Although a wide variety of tests are available, the best test is a symptom-limited, incremental test, which typically occurs by a progressive increase in work rate at a small fixed interval; however, newer, high-intensity constant load tests also are being used increasingly. The treadmill and the cycle ergometer are the most commonly used devices for this ET, but other devices also could be used. The treadmill is more commonly used in the United States, whereas the cycle ergometer is more used in Europe [8]. It is important to realize that ergometer-based tests generally produce a lower peak VO_2, usually 15%-20% less than the treadmill, because of o the use of a smaller total muscle mass [9].

Protocols generally involve a "warm-up" period with an initial low load followed by a progressive increase in effort required, typically with a stepwise progression until maximal effort is reached, followed by a "cool-down" or recovery period.

The most widely used treadmill protocol is the Bruce protocol, first described by Robert Bruce in 1973 [10]. The Bruce protocol was developed as a clinical test to evaluate patients with suspected coronary heart disease, although it can also be used to estimate cardiovascular fitness. The Bruce protocol is a standard test in cardiology and is composed of multiple exercise stages of 3 minutes each. At each stage, the gradient and speed of the treadmill are elevated to increase work output, called METs. Stage 1 of the Bruce protocol is performed at 1.7 miles per hour (mph) and a 10% gradient. Stage 2 is 2.5 mph and 12%, whereas Stage 3 goes to 3.4 mph and 14% [11,12]. The Bruce treadmill test can be used indirectly to estimate VO_2max by the use of a formula when direct ventilator gas exchange measurements are not available, thus making the test very versatile.

Although the Bruce protocol is one of the protocols most commonly used for ET, there are many other exercise protocols, one of which is the Balke protocol. In contrast to the Bruce protocol, where the gradient and the speed of the treadmill are increased each 3 minutes, in the Balke protocol, the speed remains constant at 3.3 mph whereas the slope is increased by 1% at each minute [13]. This gradual approach may be more accurate because of the more steady increase in work load; however, the test may take twice as much time to reach maximal state. Finally, when VO_2max is calculated by the use of a formula rather than with direct measurements of oxygen consumption during the Bruce protocol, it has been found that VO_2max in undertrained athletes is overestimated, whereas in well-trained athletes it is underestimated [14].

Despite the popularity and widespread use of the stepwise Bruce and Balke protocols, a ramp protocol will more consistently achieve steady-state conditions compared with other protocols [15]. Ramping protocols generate almost-imperceptible increases in treadmill speed every 15 seconds and permit increases in external work to occur in a constant or continuous fashion. Thus, increases in workload can be individualized through a wide range of patient capabilities [16].

Regardless of what protocol is used for testing, the protocol should be tailored to the individual to achieve a level of fatigue that limits exercise within 8-12 minutes [8]. When the duration of the test is less than 6 minutes, a nonlinear relationship between VO_2 and work